MULTIMEDIA UNIVERSITY

STUDENT IDENTIFICATION NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2017/2018 SESSION

BMS2024 -ADVANCED MANAGERIAL STATISTICS
(All Sections / Groups)

21 OCTOBER 2017
9.00 am – 11.00 am
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This question paper consists of 14 pages **excluding** the cover page.

2. This question paper consists of **FOUR** structured questions. Attempt **ALL** questions.

3. Students are allowed to use non-programmable scientific calculators with no restrictions.

4. A formulae list and statistical tables are attached at the end of the question paper.

5. Use **pen** to write the answers in the answer booklet provided.

QUESTION 1 [25 Marks]

a) For the following hypothesis testing, state the Type I and Type II error that might occur:

i. Airline passengers do not like it when their flights are canceled or do not leave or arrive on time. From survey of a particular airline company in 2010, the average number of complaints about such things was at least 150 complaints per year. In current year, the airline company has taken action on this matter and believes the number will improve. To verify the claim,they are conducting a test. [4 marks]

ii. An engineer hypothesizes that the mean number of defects can be decreased in a manufacturing process of compact disks by using robots instead of humans for certain tasks. The company has conducted a test to find evidence that the engineer's claim is true. [4 marks]

b) The Medical Rehabilitation Education reports that the average cost of rehabilitation for stroke victims is \$24,672. To see if the average cost of rehabilitation is different at a particular hospital, a researcher selects a random sample of 35 stroke victims at the hospital and found that the average cost is \$26,343. The standard deviation of the population is \$3251. Can we conclude that the average cost of stroke rehabilitation at a particular hospital is different from \$24,672?

Based on the above, answer the following:

i. Compute the test-statistic and the p-value for the above hypotheses. [5 marks]

ii. Based on your answers for (i), what is your statistical decision. Use p-value approach with 0.01 level of significance. [3 marks]

iii. At 0.05 level of significance, compute the probability of a Type II error. Given that the true population mean is \$26,500. [7 marks]

iv. Compute the power of the statistical test. [2 marks]

Continued...

QUESTION2 [25 Marks]

a) What is the parametric counterpart for the Wilcoxon rank sum test? State the advantages and disadvantages of applying the Wilcoxon rank sum test compared to its parametric counterpart. [6 marks]

b) According to a survey by the National Statistics Department in 2015, married persons spend an average of 13 minutes per day on phone calls, mail and e-mail, while single persons spend on average 16.6 minutes per day on these same tasks. At the 0.01 level of significance, is there any evidence to conclude that single persons spend, on average, a greater time each day communicating?.

Based on the given samples from both groups, conduct an appropriate statistical testing method. Assume that the dataset is not normally distributed.

[19 marks]

Respondent	Married	Single
1	12	10
2	10	15
3	8	17
4	14	14
5	20	25
6	9	14
7	11	10
8	18	19
9	15	20
10		22

QUESTION 3 [25 Marks]

There is high possibility that a hospital patient may acquire an infection while hospitalized. Even though all hospitals have infection control procedures and policies, the risk of infection can never be completely eliminated. There are three possible factors 0related to the likelihood of the infection. The factors are average length of patient stay at hospital (in days), average patient age and the number of x-rays are given in the hospital.

The data are analysed to assess any significant association of the factors toward patient infection risk. The summary output of the analysis is shown below:

Continued...

Regression Statistics	
Multiple R	0.702065
R Square	0.492895
Adjusted R Square	0.420452
Standard Error	0.914573
Observations	25

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	17.0731	5.691033	6.80385	0.00222
Residual	21	17.5653	0.836443		
Total	24	34.6384			

	Coefficients	*Std Error*	*t Stat*	*P-value*
Intercept	0.859184	2.540709	0.338167	0.738595
Stay	0.3082	0.146803	4.405314	0.000247
Age	-0.0230	0.043004	-0.8914	0.382817
Xray	0.01966	0.000994	3.41	0.001

a) State the multiple linear regression equation for the above data. [4 marks]

b) Determine the coefficient of determination. Interpret the value. [3 marks]

c) Determine the adjusted R^2 and interpret its meaning. [3 marks]

d) At the 5 percent level of significance, test the overall validity of the model.Use the p-value approach. [5 marks]

e) At the 5 percent level of significance, test if each independent variable is significantly related towards patient infection risk. Use the p-value approach. [6 marks]

f) What would the patient infection risk be if the patients stays 10 days at hospital, aged 48 years old and received 120 x-rays in the hospital? [4 marks]

Continued...

QUESTION 4 [25 Marks]

The sodium content of food has important implications for health. It may increases the risk of high blood pressure by having a high intake of sodium. The amount of sodium (in mg) in one serving for a random sample of three different kinds of foods is listed as below.

Condiments	Cereals	Desserts
240	260	100
130	220	180
190	290	250
180	290	250
80	200	300
70	320	360
200	140	300

Summary Output

Groups	Count	Sum	Mean	Variance
Condiments	7	1090	155.7143	4095.238
Cereal	7	1720	245.71	3928.57
Desserts	7	1740	248.57	7414.29

ANOVA

Source of Variation	SS	df	MS	F
Among Groups	39038.1	2	19519.05	3.793029
Within Groups	92628.57	18	5146.032	
Total	131666.7	20		

a) What kind of ANOVA test will be appropriate for the above study? State the required conditions or assumptions for the ANOVA test to be conducted. [5 marks]

b) At the 10 percent level of significance, is there evidence of a difference in the mean sodium amounts among condiments, cereals and desserts? Conduct an appropriate statistical procedure. [8 marks]

c) Conduct the Tukey-Kramer post-hoc test to examine which kinds of foods differ in mean sodium amounts. Use 10 percent significance level. [12 marks]

End of Paper

STATISTICAL FORMULAE

A. DESCRIPTIVE STATISTICS

Sample Mean = $\overline{X} = \dfrac{\sum_{i=1}^{n} X_i}{n}$ Sample Standard Deviation = s = $\sqrt{\dfrac{\sum_{i=1}^{n} X_i^2}{n-1} - \dfrac{\left(\sum_{i=1}^{n} X_i\right)^2}{n(n-1)}}$

where n = *number of observations*
X_i = *the* i^{th} *observation of the data*

B. HYPOTHESIS TESTING

Types of Error
Type I Error = α= P(Rejecting H_0 | H_0 is true) where, Confidence Interval = 1 - α
Type II Error = β= P(Not Rejecting H_0 | H_0 is false)

One Sample Mean Test	
σ Known	**σ Unknown**
$z = \dfrac{\overline{x} - \mu}{\sigma / \sqrt{n}}$	$t = \dfrac{\overline{x} - \mu}{s / \sqrt{n}}$

Two Sample Mean Test	
Comparing Means for Two Independent Populations	
[Standard Deviation (σ) Known] $z = \dfrac{(\overline{x}_1 - \overline{x}_2) - (\mu_1 - \mu_2)}{\sqrt{\sigma_1^2/n_1 + \sigma_2^2/n_2}}$	**[Standard Deviation (σ) Not Known]** $t = \dfrac{(\overline{x}_1 - \overline{x}_2) - (\mu_1 - \mu_2)}{\sqrt{S_p^2\left(1/n_1 + 1/n_2\right)}}$ where $S_p^2 = \dfrac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{(n_1 + n_2 - 2)}$

Two Sample Mean Test
Comparing Means for Two Paired Populations
$t = \dfrac{(\overline{D} - \mu_D)}{S_D / \sqrt{n}}$ where $\overline{D} = \dfrac{\sum_{i=1}^{n} D_i}{n}$ and $S_D = \sqrt{\dfrac{\sum_{i=1}^{n} D_i^2}{n-1} - \dfrac{\left(\sum_{i=1}^{n} D_i\right)^2}{n(n-1)}}$

Non-Parametric Analysis

Wilcoxon Rank Sum Test	Wilcoxon Signed Rank Sum Test
$Z = \dfrac{(T_1 - \mu_{T_1})}{\sigma_{T_1}}$ where	$Z = \dfrac{(T_+ - \mu_{T_+})}{\sigma_{T_+}}$ where
$\mu_{T1} = \dfrac{n_1(n+1)}{2}$ and	$\mu_{T+} = \dfrac{n(n+1)}{4}$ and
$\sigma_{T_1} = \sqrt{\dfrac{n_1 n_2 (n+1)}{12}}$ where $n = n_1 + n_2$	$\sigma_{T_+} = \sqrt{\dfrac{n(n+1)(2n+1)}{24}}$

Kruskal-Wallis Rank Test

$$H = \left[\frac{12}{n(n+1)}\sum_{j=1}^{c}\frac{T_j^2}{n_j}\right] - 3(n+1)$$ where the critical value is χ^2 with $df = c - 1$

Check ranking sum: $\sum T_j = n(n+1)/2$

Chi-Square Test

$$\chi^2 = \sum^{n}\frac{(O-E)^2}{E}$$

where O = Frequency of Observed Values *and* *E = Frequency of Expected Values*

with $df = c - 1$ *where c = number of categories*
or
with $df = (r-1)(c-1)$ *where r = number of rows and c = number of columns*

C. ANALYSIS OF VARIANCE (ANOVA)

One-Way ANOVA

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F-statistic
Among Groups	$c - 1$	SSA	MSA = SSA/c-1	MSA/MSW
Within Groups	$n - c$	SSW	MSW = SSW/n-c	
Total	$n - 1$	SST		

$$SST = \sum_{j=1}^{c}\sum_{i=1}^{n_j}\left(X_{ij} - \overline{\overline{X}}\right)^2$$ *or alternative formula:* $$SST = \left(\sum_{j=1}^{c}\sum_{i=1}^{n_j}X_{ij}^2\right) - \frac{\left(\sum_{j=1}^{c}\sum_{i=1}^{n_j}X_{ij}\right)^2}{n}$$

$$SSA = \sum_{j=1}^{c} n_j\left(\overline{X}_j - \overline{\overline{X}}\right)^2$$ *and SSW = SST - SSA*

where n = number of observations, c = number of groups and $\overline{\overline{X}}$ *= overall mean*

Tukey-Kramer Procedure

$$\text{Critical Range} = Q_U \sqrt{\frac{MSW}{2}\left[\frac{1}{n_i}+\frac{1}{n_j}\right]}$$

where Q_u = the upper tail critical value from a Studentized Range Distribution having (c) degrees of freedom in the numerator and (n – c) degrees of freedom in the denominator at a given level of significance

Two-Way ANOVA

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F-statistic
A	$r-1$	SSA	MSA = SSA/$(r-1)$	MSA / MSE
B	$c-1$	SSB	MSB = SSB/$(c-1)$	MSB / MSE
AB	$(r-1)(c-1)$	SSAB	MSAB = SSAB/$(r-1)(c-1)$	MSAB / MSE
Error	$rc\,(n-1)$	SSE	MSE = SSE/$rc(n'-1)$	
Total	$n-1$	SST		

where,

Factor A levels are represented by the rows and Factor B levels are represented by the columns and
n = number of observations
c = number of columns
r = number of rows
n' = number of replicates

$$SST = \sum_{i=1}^{r}\sum_{j=1}^{c}\sum_{k=1}^{n'}\left(X_{ijk}-\overline{\overline{X}}\right)^2 \qquad SSA = cn'\sum_{i=1}^{r}\left(\overline{X}_i-\overline{\overline{X}}\right)^2$$

$$SSB = rn'\sum_{j=1}^{c}\left(\overline{X}j-\overline{\overline{X}}\right)^2 \qquad \text{where } \overline{\overline{X}} = \textit{overall mean}$$

$$SSE = (n'-1)\left[S_1^2+S_2^2+\dots\dots+S_k^2\right] \qquad \text{where } S_i^2 = \text{variance of each block}$$

D. REGRESSION ANALYSIS

Multiple Linear Regression

Population Model: $Y = \beta_0+\beta_1X_1+\beta_2X_2+\dots\dots+\beta_kX_k+\varepsilon$

Sample Model: $\hat{y} = b_0+b_1x_1+b_2x_2+\dots\dots+b_kx_k+e$

Adjusted R-Square $=1-\left[\frac{(1-R^2)(n-1)}{(n-p-1)}\right]$ where p = number of independent/predictor variables

ANOVA Table for Regression			
Source	**Degrees of Freedom**	**Sum of Squares**	**Mean Squares**
Regression	p	SSR	MSR = SSR/p
Error/Residual	$n-p-1$	SSE	MSE = SSE/$(n-p-1)$
Total	$n-1$	SST	

Test Statistic for Significance of the Overall Regression Model

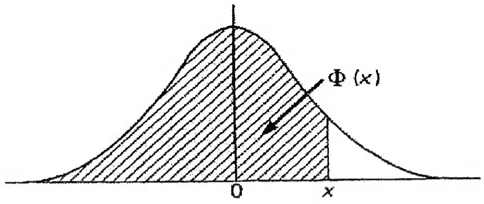
F = MSR/MSE

Test Statistic for Significance of Each Predictor Variable

$t_i = \dfrac{b_i}{S_{b_i}}$ and the critical value $= \pm t_{\alpha/2,(n-p-1)}$

TABLE 4. THE NORMAL DISTRIBUTION FUNCTION

The function tabulated is $\Phi(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{1}{2}t^2}\,dt$. $\Phi(x)$ is the probability that a random variable, normally distributed with zero mean and unit variance, will be less than or equal to x. When $x < 0$ use $\Phi(x) = 1 - \Phi(-x)$, as the normal distribution with zero mean and unit variance is symmetric about zero.



x	$\Phi(x)$	x	$\Phi(x)$	x	$\Phi(x)$	x	$\Phi(x)$	x	$\Phi(x)$	x	$\Phi(x)$
0·00	0·5000	0·40	0·6554	0·80	0·7881	1·20	0·8849	1·60	0·9452	2·00	0·97725
·01	·5040	·41	·6591	·81	·7910	·21	·8869	·61	·9463	·01	·97778
·02	·5080	·42	·6628	·82	·7939	·22	·8888	·62	·9474	·02	·97831
·03	·5120	·43	·6664	·83	·7967	·23	·8907	·63	·9484	·03	·97882
·04	·5160	·44	·6700	·84	·7995	·24	·8925	·64	·9495	·04	·97932
0·05	0·5199	0·45	0·6736	0·85	0·8023	1·25	0·8944	1·65	0·9505	2·05	0·97982
·06	·5239	·46	·6772	·86	·8051	·26	·8962	·66	·9515	·06	·98030
·07	·5279	·47	·6808	·87	·8078	·27	·8980	·67	·9525	·07	·98077
·08	·5319	·48	·6844	·88	·8106	·28	·8997	·68	·9535	·08	·98124
·09	·5359	·49	·6879	·89	·8133	·29	·9015	·69	·9545	·09	·98169
0·10	0·5398	0·50	0·6915	0·90	0·8159	1·30	0·9032	1·70	0·9554	2·10	0·98214
·11	·5438	·51	·6950	·91	·8186	·31	·9049	·71	·9564	·11	·98257
·12	·5478	·52	·6985	·92	·8212	·32	·9066	·72	·9573	·12	·98300
·13	·5517	·53	·7019	·93	·8238	·33	·9082	·73	·9582	·13	·98341
·14	·5557	·54	·7054	·94	·8264	·34	·9099	·74	·9591	·14	·98382
0·15	0·5596	0·55	0·7088	0·95	0·8289	1·35	0·9115	1·75	0·9599	2·15	0·98422
·16	·5636	·56	·7123	·96	·8315	·36	·9131	·76	·9608	·16	·98461
·17	·5675	·57	·7157	·97	·8340	·37	·9147	·77	·9616	·17	·98500
·18	·5714	·58	·7190	·98	·8365	·38	·9162	·78	·9625	·18	·98537
·19	·5753	·59	·7224	·99	·8389	·39	·9177	·79	·9633	·19	·98574
0·20	0·5793	0·60	0·7257	1·00	0·8413	1·40	0·9192	1·80	0·9641	2·20	0·98610
·21	·5832	·61	·7291	·01	·8438	·41	·9207	·81	·9649	·21	·98645
·22	·5871	·62	·7324	·02	·8461	·42	·9222	·82	·9656	·22	·98679
·23	·5910	·63	·7357	·03	·8485	·43	·9236	·83	·9664	·23	·98713
·24	·5948	·64	·7389	·04	·8508	·44	·9251	·84	·9671	·24	·98745
0·25	0·5987	0·65	0·7422	1·05	0·8531	1·45	0·9265	1·85	0·9678	2·25	0·98778
·26	·6026	·66	·7454	·06	·8554	·46	·9279	·86	·9686	·26	·98809
·27	·6064	·67	·7486	·07	·8577	·47	·9292	·87	·9693	·27	·98840
·28	·6103	·68	·7517	·08	·8599	·48	·9306	·88	·9699	·28	·98870
·29	·6141	·69	·7549	·09	·8621	·49	·9319	·89	·9706	·29	·98899
0·30	0·6179	0·70	0·7580	1·10	0·8643	1·50	0·9332	1·90	0·9713	2·30	0·98928
·31	·6217	·71	·7611	·11	·8665	·51	·9345	·91	·9719	·31	·98956
·32	·6255	·72	·7642	·12	·8686	·52	·9357	·92	·9726	·32	·98983
·33	·6293	·73	·7673	·13	·8708	·53	·9370	·93	·9732	·33	·99010
·34	·6331	·74	·7704	·14	·8729	·54	·9382	·94	·9738	·34	·99036
0·35	0·6368	0·75	0·7734	1·15	0·8749	1·55	0·9394	1·95	0·9744	2·35	0·99061
·36	·6406	·76	·7764	·16	·8770	·56	·9406	·96	·9750	·36	·99086
·37	·6443	·77	·7794	·17	·8790	·57	·9418	·97	·9756	·37	·99111
·38	·6480	·78	·7823	·18	·8810	·58	·9429	·98	·9761	·38	·99134
·39	·6517	·79	·7852	·19	·8830	·59	·9441	·99	·9767	·39	·99158
0·40	0·6554	0·80	0·7881	1·20	0·8849	1·60	0·9452	2·00	0·9772	2·40	0·99180

TABLE 4. THE NORMAL DISTRIBUTION FUNCTION

x	$\Phi(x)$	x	$\Phi(x)$	x	$\Phi(x)$	x	$\Phi(x)$	x	$\Phi(x)$	x	$\Phi(x)$
2.40	0.99180	2.55	0.99461	2.70	0.99653	2.85	0.99781	3.00	0.99865	3.15	0.99918
.41	.99202	.56	.99477	.71	.99664	.86	.99788	.01	.99869	.16	.99921
.42	.99224	.57	.99492	.72	.99674	.87	.99795	.02	.99874	.17	.99924
.43	.99245	.58	.99506	.73	.99683	.88	.99801	.03	.99878	.18	.99926
.44	.99266	.59	.99520	.74	.99693	.89	.99807	.04	.99882	.19	.99929
2.45	0.99286	2.60	0.99534	2.75	0.99702	2.90	0.99813	3.05	0.99886	3.20	0.99931
.46	.99305	.61	.99547	.76	.99711	.91	.99819	.06	.99889	.21	.99934
.47	.99324	.62	.99560	.77	.99720	.92	.99825	.07	.99893	.22	.99936
.48	.99343	.63	.99573	.78	.99728	.93	.99831	.08	.99896	.23	.99938
.49	.99361	.64	.99585	.79	.99736	.94	.99836	.09	.99900	.24	.99940
2.50	0.99379	2.65	0.99598	2.80	0.99744	2.95	0.99841	3.10	0.99903	3.25	0.99942
.51	.99396	.66	.99609	.81	.99752	.96	.99846	.11	.99906	.26	.99944
.52	.99413	.67	.99621	.82	.99760	.97	.99851	.12	.99910	.27	.99946
.53	.99430	.68	.99632	.83	.99767	.98	.99856	.13	.99913	.28	.99948
.54	.99446	.69	.99643	.84	.99774	.99	.99861	.14	.99916	.29	.99950
2.55	0.99461	2.70	0.99653	2.85	0.99781	3.00	0.99865	3.15	0.99918	3.30	0.99952

The critical table below gives on the left the range of values of x for which $\Phi(x)$ takes the value on the right, correct to the last figure given; in critical cases, take the upper of the two values of $\Phi(x)$ indicated.

			0.9994		0.99990		0.99995
3.075		3.263		3.731		3.916	
	0.9990		0.9995		0.99991		0.99996
3.105		3.320		3.759		3.976	
	0.9991		0.9996		0.99992		0.99997
3.138		3.389		3.791		4.055	
	0.9992		0.9997		0.99993		0.99998
3.174		3.480		3.826		4.173	
	0.9993		0.9998		0.99994		0.99999
3.215		3.615		3.867		4.417	
	0.9994		0.9999		0.99995		1.00000

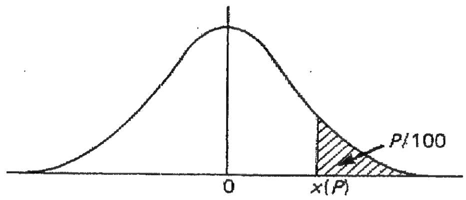
When $x > 3.3$ the formula $1-\Phi(x) \doteqdot \frac{e^{-\frac{1}{2}x^2}}{x\sqrt{2\pi}}\left[1-\frac{1}{x^2}+\frac{3}{x^4}-\frac{15}{x^6}+\frac{105}{x^8}\right]$ is very accurate, with relative error less than $945/x^{10}$.

TABLE 5. PERCENTAGE POINTS OF THE NORMAL DISTRIBUTION

This table gives percentage points $x(P)$ defined by the equation

$$\frac{P}{100} = \frac{1}{\sqrt{2\pi}}\int_{x(P)}^{\infty} e^{-\frac{1}{2}t^2}\,dt.$$

If X is a variable, normally distributed with zero mean and unit variance, $P/100$ is the probability that $X \geqslant x(P)$. The lower P per cent points are given by symmetry as $-x(P)$, and the probability that $|X| \geqslant x(P)$ is $2P/100$.



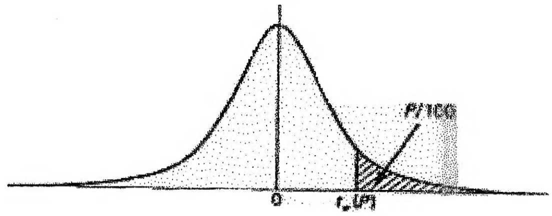
P	$x(P)$	P	$x(P)$	P	$x(P)$	P	$x(P)$	P	$x(P)$	P	$x(P)$
50	0.0000	5.0	1.6449	3.0	1.8808	2.0	2.0537	1.0	2.3263	0.10	3.0902
45	0.1257	4.8	1.6646	2.9	1.8957	1.9	2.0749	0.9	2.3656	0.09	3.1214
40	0.2533	4.6	1.6849	2.8	1.9110	1.8	2.0969	0.8	2.4089	0.08	3.1559
35	0.3853	4.4	1.7060	2.7	1.9268	1.7	2.1201	0.7	2.4573	0.07	3.1947
30	0.5244	4.2	1.7279	2.6	1.9431	1.6	2.1444	0.6	2.5121	0.06	3.2389
25	0.6745	4.0	1.7507	2.5	1.9600	1.5	2.1701	0.5	2.5758	0.05	3.2905
20	0.8416	3.8	1.7744	2.4	1.9774	1.4	2.1973	0.4	2.6521	0.01	3.7190
15	1.0364	3.6	1.7991	2.3	1.9954	1.3	2.2262	0.3	2.7478	0.005	3.8906
10	1.2816	3.4	1.8250	2.2	2.0141	1.2	2.2571	0.2	2.8782	0.001	4.2649
5	1.6449	3.2	1.8522	2.1	2.0335	1.1	2.2904	0.1	3.0902	0.0005	4.4172

TABLE 10. PERCENTAGE POINTS OF THE t-DISTRIBUTION

This table gives percentage points $t_\nu(P)$ defined by the equation

$$\frac{P}{100} = \frac{1}{\sqrt{\nu\pi}} \frac{\Gamma(\frac{1}{2}\nu+\frac{1}{2})}{\Gamma(\frac{1}{2}\nu)} \int_{t_\nu(P)}^{\infty} \frac{dt}{(1+t^2/\nu)^{\frac{1}{2}(\nu+1)}}.$$

Let X_1 and X_2 be independent random variables having a normal distribution with zero mean and unit variance and a χ^2-distribution with ν degrees of freedom respectively; then $t = X_1/\sqrt{X_2/\nu}$ has Student's t-distribution with ν degrees of freedom, and the probability that $t \geqslant t_\nu(P)$ is $P/100$. The lower percentage points are given by symmetry as $-t_\nu(P)$, and the probability that $|t| \geqslant t_\nu(P)$ is $2P/100$.



The limiting distribution of t as ν tends to infinity is the normal distribution with zero mean and unit variance. When ν is large interpolation in ν should be harmonic.

P	40	30	25	20	15	10	5	2.5	1	0.5	0.1	0.05
ν = 1	0.3249	0.7265	1.0000	1.3764	1.963	3.078	6.314	12.71	31.82	63.66	318.3	636.6
2	0.2887	0.6172	0.8165	1.0607	1.386	1.886	2.920	4.303	6.965	9.925	22.33	31.60
3	0.2767	0.5844	0.7649	0.9785	1.250	1.638	2.353	3.182	4.541	5.841	10.21	12.92
4	0.2707	0.5686	0.7407	0.9410	1.190	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	0.2672	0.5594	0.7267	0.9195	1.156	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	0.2648	0.5534	0.7176	0.9057	1.134	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	0.2632	0.5491	0.7111	0.8960	1.119	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	0.2619	0.5459	0.7064	0.8889	1.108	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	0.2610	0.5435	0.7027	0.8834	1.100	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	0.2602	0.5415	0.6998	0.8791	1.093	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	0.2596	0.5399	0.6974	0.8755	1.088	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	0.2590	0.5386	0.6955	0.8726	1.083	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	0.2586	0.5375	0.6938	0.8702	1.079	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	0.2582	0.5366	0.6924	0.8681	1.076	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	0.2579	0.5357	0.6912	0.8662	1.074	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	0.2576	0.5350	0.6901	0.8647	1.071	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	0.2573	0.5344	0.6892	0.8633	1.069	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	0.2571	0.5338	0.6884	0.8620	1.067	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	0.2569	0.5333	0.6876	0.8610	1.066	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	0.2567	0.5329	0.6870	0.8600	1.064	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	0.2566	0.5325	0.6864	0.8591	1.063	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	0.2564	0.5321	0.6858	0.8583	1.061	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	0.2563	0.5317	0.6853	0.8575	1.060	1.319	1.714	2.069	2.500	2.807	3.485	3.768
24	0.2562	0.5314	0.6848	0.8569	1.059	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	0.2561	0.5312	0.6844	0.8562	1.058	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	0.2560	0.5309	0.6840	0.8557	1.058	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	0.2559	0.5306	0.6837	0.8551	1.057	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	0.2558	0.5304	0.6834	0.8546	1.056	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	0.2557	0.5302	0.6830	0.8542	1.055	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	0.2556	0.5300	0.6828	0.8538	1.055	1.310	1.697	2.042	2.457	2.750	3.385	3.646
32	0.2555	0.5297	0.6822	0.8530	1.054	1.309	1.694	2.037	2.449	2.738	3.365	3.622
34	0.2553	0.5294	0.6818	0.8523	1.052	1.307	1.691	2.032	2.441	2.728	3.348	3.601
36	0.2552	0.5291	0.6814	0.8517	1.052	1.306	1.688	2.028	2.434	2.719	3.333	3.582
38	0.2551	0.5288	0.6810	0.8512	1.051	1.304	1.686	2.024	2.429	2.712	3.319	3.566
40	0.2550	0.5286	0.6807	0.8507	1.050	1.303	1.684	2.021	2.423	2.704	3.307	3.551
50	0.2547	0.5278	0.6794	0.8489	1.047	1.299	1.676	2.009	2.403	2.678	3.261	3.496
60	0.2545	0.5272	0.6786	0.8477	1.045	1.296	1.671	2.000	2.390	2.660	3.232	3.460
120	0.2539	0.5258	0.6765	0.8446	1.041	1.289	1.658	1.980	2.358	2.617	3.160	3.373
∞	0.2533	0.5244	0.6745	0.8416	1.036	1.282	1.645	1.960	2.326	2.576	3.090	3.291

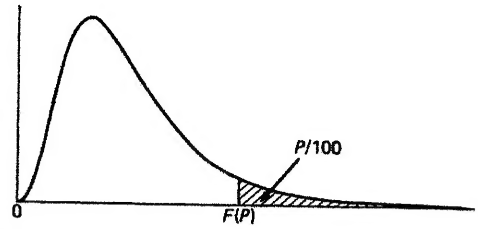
TABLE 12(*a*). 10 PER CENT POINTS OF THE *F*-DISTRIBUTION

The function tabulated is $F(P) = F(P|\nu_1, \nu_2)$ defined by the equation

$$\frac{P}{100} = \frac{\Gamma(\frac{1}{2}\nu_1+\frac{1}{2}\nu_2)}{\Gamma(\frac{1}{2}\nu_1)\,\Gamma(\frac{1}{2}\nu_2)}\,\nu_1^{\frac{1}{2}\nu_1}\,\nu_2^{\frac{1}{2}\nu_2}\int_{F(P)}^{\infty}\frac{F^{\frac{1}{2}\nu_1-1}}{(\nu_2+\nu_1F)^{\frac{1}{2}(\nu_1+\nu_2)}}\,dF,$$

for $P = 10$, 5, 2.5, 1, 0.5 and 0.1. The lower percentage points, that is the values $F'(P) = F'(P|\nu_1, \nu_2)$ such that the probability that $F \leqslant F'(P)$ is equal to $P/100$, may be found by the formula

$$F'(P|\nu_1, \nu_2) = 1/F(P|\nu_2, \nu_1).$$

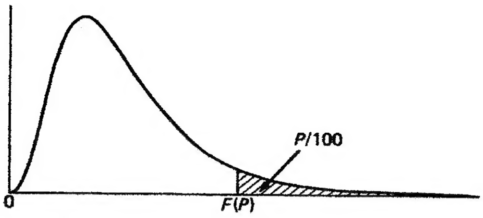


(This shape applies only when $\nu_1 \geqslant 3$. When $\nu_1 < 3$ the mode is at the origin.)

ν_2 \ $\nu_1 =$	1	2	3	4	5	6	7	8	10	12	24	∞
$\nu_2 =$ 1	39.86	49.50	53.59	55.83	57.24	58.20	58.91	59.44	60.19	60.71	62.00	63.33
2	8.526	9.000	9.162	9.243	9.293	9.326	9.349	9.367	9.392	9.408	9.450	9.491
3	5.538	5.462	5.391	5.343	5.309	5.285	5.266	5.252	5.230	5.216	5.176	5.134
4	4.545	4.325	4.191	4.107	4.051	4.010	3.979	3.955	3.920	3.896	3.831	3.761
5	4.060	3.780	3.619	3.520	3.453	3.405	3.368	3.339	3.297	3.268	3.191	3.105
6	3.776	3.463	3.289	3.181	3.108	3.055	3.014	2.983	2.937	2.905	2.818	2.722
7	3.589	3.257	3.074	2.961	2.883	2.827	2.785	2.752	2.703	2.668	2.575	2.471
8	3.458	3.113	2.924	2.806	2.726	2.668	2.624	2.589	2.538	2.502	2.404	2.293
9	3.360	3.006	2.813	2.693	2.611	2.551	2.505	2.469	2.416	2.379	2.277	2.159
10	3.285	2.924	2.728	2.605	2.522	2.461	2.414	2.377	2.323	2.284	2.178	2.055
11	3.225	2.860	2.660	2.536	2.451	2.389	2.342	2.304	2.248	2.209	2.100	1.972
12	3.177	2.807	2.606	2.480	2.394	2.331	2.283	2.245	2.188	2.147	2.036	1.904
13	3.136	2.763	2.560	2.434	2.347	2.283	2.234	2.195	2.138	2.097	1.983	1.846
14	3.102	2.726	2.522	2.395	2.307	2.243	2.193	2.154	2.095	2.054	1.938	1.797
15	3.073	2.695	2.490	2.361	2.273	2.208	2.158	2.119	2.059	2.017	1.899	1.755
16	3.048	2.668	2.462	2.333	2.244	2.178	2.128	2.088	2.028	1.985	1.866	1.718
17	3.026	2.645	2.437	2.308	2.218	2.152	2.102	2.061	2.001	1.958	1.836	1.686
18	3.007	2.624	2.416	2.286	2.196	2.130	2.079	2.038	1.977	1.933	1.810	1.657
19	2.990	2.606	2.397	2.266	2.176	2.109	2.058	2.017	1.956	1.912	1.787	1.631
20	2.975	2.589	2.380	2.249	2.158	2.091	2.040	1.999	1.937	1.892	1.767	1.607
21	2.961	2.575	2.365	2.233	2.142	2.075	2.023	1.982	1.920	1.875	1.748	1.586
22	2.949	2.561	2.351	2.219	2.128	2.060	2.008	1.967	1.904	1.859	1.731	1.567
23	2.937	2.549	2.339	2.207	2.115	2.047	1.995	1.953	1.890	1.845	1.716	1.549
24	2.927	2.538	2.327	2.195	2.103	2.035	1.983	1.941	1.877	1.832	1.702	1.533
25	2.918	2.528	2.317	2.184	2.092	2.024	1.971	1.929	1.866	1.820	1.689	1.518
26	2.909	2.519	2.307	2.174	2.082	2.014	1.961	1.919	1.855	1.809	1.677	1.504
27	2.901	2.511	2.299	2.165	2.073	2.005	1.952	1.909	1.845	1.799	1.666	1.491
28	2.894	2.503	2.291	2.157	2.064	1.996	1.943	1.900	1.836	1.790	1.656	1.478
29	2.887	2.495	2.283	2.149	2.057	1.988	1.935	1.892	1.827	1.781	1.647	1.467
30	2.881	2.489	2.276	2.142	2.049	1.980	1.927	1.884	1.819	1.773	1.638	1.456
32	2.869	2.477	2.263	2.129	2.036	1.967	1.913	1.870	1.805	1.758	1.622	1.437
34	2.859	2.466	2.252	2.118	2.024	1.955	1.901	1.858	1.793	1.745	1.608	1.419
36	2.850	2.456	2.243	2.108	2.014	1.945	1.891	1.847	1.781	1.734	1.595	1.404
38	2.842	2.448	2.234	2.099	2.005	1.935	1.881	1.838	1.772	1.724	1.584	1.390
40	2.835	2.440	2.226	2.091	1.997	1.927	1.873	1.829	1.763	1.715	1.574	1.377
60	2.791	2.393	2.177	2.041	1.946	1.875	1.819	1.775	1.707	1.657	1.511	1.291
120	2.748	2.347	2.130	1.992	1.896	1.824	1.767	1.722	1.652	1.601	1.447	1.193
∞	2.706	2.303	2.084	1.945	1.847	1.774	1.717	1.670	1.599	1.546	1.383	1.000

TABLE 12(*b*). 5 PER CENT POINTS OF THE *F*-DISTRIBUTION

If $F = \frac{X_1}{\nu_1} \Big/ \frac{X_2}{\nu_2}$, where X_1 and X_2 are independent random variables distributed as χ^2 with ν_1 and ν_2 degrees of freedom respectively, then the probabilities that $F \geqslant F(P)$ and that $F \leqslant F'(P)$ are both equal to $P/100$. Linear interpolation in ν_1 and ν_2 will generally be sufficiently accurate except when either $\nu_1 > 12$ or $\nu_2 > 40$, when harmonic interpolation should be used.



(This shape applies only when $\nu_1 \geqslant 3$. When $\nu_1 < 3$ the mode is at the origin.)

$\nu_1 =$	1	2	3	4	5	6	7	8	10	12	24	∞
$\nu_2 =$ 1	161·4	199·5	215·7	224·6	230·2	234·0	236·8	238·9	241·9	243·9	249·1	254·3
2	18·51	19·00	19·16	19·25	19·30	19·33	19·35	19·37	19·40	19·41	19·45	19·50
3	10·13	9·552	9·277	9·117	9·013	8·941	8·887	8·845	8·786	8·745	8·639	8·526
4	7·709	6·944	6·591	6·388	6·256	6·163	6·094	6·041	5·964	5·912	5·774	5·628
5	6·608	5·786	5·409	5·192	5·050	4·950	4·876	4·818	4·735	4·678	4·527	4·365
6	5·987	5·143	4·757	4·534	4·387	4·284	4·207	4·147	4·060	4·000	3·841	3·669
7	5·591	4·737	4·347	4·120	3·972	3·866	3·787	3·726	3·637	3·575	3·410	3·230
8	5·318	4·459	4·066	3·838	3·687	3·581	3·500	3·438	3·347	3·284	3·115	2·928
9	5·117	4·256	3·863	3·633	3·482	3·374	3·293	3·230	3·137	3·073	2·900	2·707
10	4·965	4·103	3·708	3·478	3·326	3·217	3·135	3·072	2·978	2·913	2·737	2·538
11	4·844	3·982	3·587	3·357	3·204	3·095	3·012	2·948	2·854	2·788	2·609	2·404
12	4·747	3·885	3·490	3·259	3·106	2·996	2·913	2·849	2·753	2·687	2·505	2·296
13	4·667	3·806	3·411	3·179	3·025	2·915	2·832	2·767	2·671	2·604	2·420	2·206
14	4·600	3·739	3·344	3·112	2·958	2·848	2·764	2·699	2·602	2·534	2·349	2·131
15	4·543	3·682	3·287	3·056	2·901	2·790	2·707	2·641	2·544	2·475	2·288	2·066
16	4·494	3·634	3·239	3·007	2·852	2·741	2·657	2·591	2·494	2·425	2·235	2·010
17	4·451	3·592	3·197	2·965	2·810	2·699	2·614	2·548	2·450	2·381	2·190	1·960
18	4·414	3·555	3·160	2·928	2·773	2·661	2·577	2·510	2·412	2·342	2·150	1·917
19	4·381	3·522	3·127	2·895	2·740	2·628	2·544	2·477	2·378	2·308	2·114	1·878
20	4·351	3·493	3·098	2·866	2·711	2·599	2·514	2·447	2·348	2·278	2·082	1·843
21	4·325	3·467	3·072	2·840	2·685	2·573	2·488	2·420	2·321	2·250	2·054	1·812
22	4·301	3·443	3·049	2·817	2·661	2·549	2·464	2·397	2·297	2·226	2·028	1·783
23	4·279	3·422	3·028	2·796	2·640	2·528	2·442	2·375	2·275	2·204	2·005	1·757
24	4·260	3·403	3·009	2·776	2·621	2·508	2·423	2·355	2·255	2·183	1·984	1·733
25	4·242	3·385	2·991	2·759	2·603	2·490	2·405	2·337	2·236	2·165	1·964	1·711
26	4·225	3·369	2·975	2·743	2·587	2·474	2·388	2·321	2·220	2·148	1·946	1·691
27	4·210	3·354	2·960	2·728	2·572	2·459	2·373	2·305	2·204	2·132	1·930	1·672
28	4·196	3·340	2·947	2·714	2·558	2·445	2·359	2·291	2·190	2·118	1·915	1·654
29	4·183	3·328	2·934	2·701	2·545	2·432	2·346	2·278	2·177	2·104	1·901	1·638
30	4·171	3·316	2·922	2·690	2·534	2·421	2·334	2·266	2·165	2·092	1·887	1·622
32	4·149	3·295	2·901	2·668	2·512	2·399	2·313	2·244	2·142	2·070	1·864	1·594
34	4·130	3·276	2·883	2·650	2·494	2·380	2·294	2·225	2·123	2·050	1·843	1·569
36	4·113	3·259	2·866	2·634	2·477	2·364	2·277	2·209	2·106	2·033	1·824	1·547
38	4·098	3·245	2·852	2·619	2·463	2·349	2·262	2·194	2·091	2·017	1·808	1·527
40	4·085	3·232	2·839	2·606	2·449	2·336	2·249	2·180	2·077	2·003	1·793	1·509
60	4·001	3·150	2·758	2·525	2·368	2·254	2·167	2·097	1·993	1·917	1·700	1·389
120	3·920	3·072	2·680	2·447	2·290	2·175	2·087	2·016	1·910	1·834	1·608	1·254
∞	3·841	2·996	2·605	2·372	2·214	2·099	2·010	1·938	1·831	1·752	1·517	1·000

Tables of the Studentized Range, alpha= 0.10

Denominator df	Numerator 2	3	4	5	6	7	8	9	10	11	12	13
1	8.93	13.44	16.36	18.49	20.15	21.50	22.64	23.62	24.48	25.24	25.92	26.54
2	4.13	5.73	6.77	7.54	8.14	8.63	9.05	9.41	9.73	10.01	10.26	10.49
3	3.33	4.47	5.20	5.74	6.16	6.51	6.81	7.06	7.29	7.49	7.67	7.83
4	3.02	3.98	4.59	5.04	5.39	5.68	5.93	6.14	6.33	6.49	6.65	6.78
5	2.85	3.72	4.26	4.66	4.98	5.24	5.46	5.65	5.82	5.97	6.10	6.22
6	2.75	3.56	4.07	4.44	4.73	4.97	5.17	5.34	5.50	5.64	5.76	5.88
7	2.68	3.45	3.93	4.28	4.56	4.78	4.97	5.14	5.28	5.41	5.53	5.64
8	2.63	3.37	3.83	4.17	4.43	4.65	4.83	4.99	5.13	5.25	5.36	5.46
9	2.59	3.32	3.76	4.08	4.34	4.55	4.72	4.87	5.01	5.13	5.23	5.33
10	2.56	3.27	3.70	4.02	4.26	4.47	4.64	4.78	4.91	5.03	5.13	5.23
11	2.54	3.23	3.66	3.97	4.21	4.40	4.57	4.71	4.84	4.95	5.05	5.15
12	2.52	3.20	3.62	3.92	4.16	4.35	4.51	4.65	4.78	4.89	4.99	5.08
13	2.50	3.18	3.59	3.89	4.12	4.30	4.46	4.60	4.72	4.83	4.93	5.02
14	2.49	3.16	3.56	3.85	4.08	4.27	4.42	4.56	4.68	4.79	4.88	4.97
15	2.48	3.14	3.54	3.83	4.05	4.24	4.39	4.52	4.64	4.75	4.84	4.93
16	2.47	3.12	3.52	3.80	4.03	4.21	4.36	4.49	4.61	4.71	4.81	4.89
17	2.46	3.11	3.50	3.78	4.00	4.18	4.33	4.46	4.58	4.68	4.77	4.86
18	2.45	3.10	3.49	3.77	3.98	4.16	4.31	4.44	4.55	4.65	4.75	4.83
19	2.45	3.09	3.47	3.75	3.97	4.14	4.29	4.42	4.53	4.63	4.72	4.80
20	2.44	3.08	3.46	3.74	3.95	4.12	4.27	4.40	4.51	4.61	4.70	4.78
21	2.43	3.07	3.45	3.72	3.94	4.11	4.26	4.38	4.49	4.59	4.68	4.76
22	2.43	3.06	3.44	3.71	3.92	4.10	4.24	4.36	4.47	4.57	4.66	4.74
23	2.42	3.05	3.43	3.70	3.91	4.08	4.23	4.35	4.46	4.56	4.64	4.72
24	2.42	3.05	3.42	3.69	3.90	4.07	4.21	4.34	4.45	4.54	4.63	4.71
25	2.42	3.04	3.42	3.68	3.89	4.06	4.20	4.32	4.43	4.53	4.61	4.69
26	2.41	3.04	3.41	3.68	3.88	4.05	4.19	4.31	4.42	4.52	4.60	4.68
27	2.41	3.03	3.40	3.67	3.87	4.04	4.18	4.30	4.41	4.50	4.59	4.67
28	2.41	3.03	3.40	3.66	3.87	4.03	4.17	4.29	4.40	4.49	4.58	4.66
29	2.40	3.02	3.39	3.65	3.86	4.02	4.16	4.28	4.39	4.48	4.57	4.65
30	2.40	3.02	3.39	3.65	3.85	4.02	4.16	4.28	4.38	4.47	4.56	4.64
40	2.38	2.99	3.35	3.61	3.80	3.96	4.10	4.22	4.32	4.41	4.49	4.56
60	2.36	2.96	3.31	3.56	3.76	3.91	4.04	4.16	4.25	4.34	4.42	4.49
80	2.35	2.95	3.29	3.54	3.73	3.89	4.01	4.13	4.22	4.31	4.39	4.46
120	2.34	2.93	3.28	3.52	3.71	3.86	3.99	4.10	4.19	4.28	4.35	4.42
240	2.34	2.92	3.26	3.50	3.68	3.83	3.96	4.07	4.16	4.24	4.32	4.39
∞	2.33	2.90	3.24	3.48	3.66	3.81	3.93	4.04	4.13	4.21	4.29	4.35